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Weekly cycle of lightning: Evidence of storm invigoration by pollution

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[1] We have examined summertime 1998–2009 U.S. lightning data from the National Lightning Detection Network (NLDN) to look for weekly cycles in lightning activity. As was found by Bell et al. (2008) for rain over the southeast U.S., there is a significant weekly cycle in afternoon lightning activity that peaks in the middle of the week there. The weekly cycle appears to be reduced over population centers. Lightning activity peaks on weekends over waters near the SE U.S. The statistical significance of weekly cycles over the western half of the country is generally small. We found no evidence of a weekly cycle of synoptic-scale forcing that might explain these patterns. The lightning behavior is entirely consistent with the explanation suggested by Bell et al. (2008) for the cycles in rainfall and other atmospheric data from the SE U.S., that aerosols can cause storms to intensify in humid, convectively unstable environments.
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1. Introduction

[2] *Bell et al.* [2008, hereafter B08] recently reported strong evidence that average rainfall is highest during the middle of the week (Tue–Thu) over the non-coastal southeast U.S. during the summer months of 1998–2005. The midweek increase was due in part to increases of the area with rain and in part to increases in the intensity of rain where it was raining. A theory was proposed to explain the changes in rain statistics with the day of the week, attributing it to the effects of weekly variations in pollution (U.S. pollution tends to be highest in the middle of the work week). This theory suggests that increased pollution in the moist, convectively unstable environment over the summertime SE U.S. leads to more intense storms through increased vertical transport of water in the form of smaller droplets to altitudes where additional latent heat is released by freezing of the water [*Rosenfeld et al.*, 2008]. The theory suggested that the effect should be particularly pronounced in the afternoon hours, when convective potential is at its highest, and that midweek storms should tend to climb to higher altitudes, both of which were seen by B08 in Tropical Rainfall Measuring Mission (TRMM) satellite data. The midweek increase in storm heights was recently confirmed by *Bell et al.* [2009]. A slightly weaker weekly cycle was seen in rain-gauge data from the area. A weekly cycle in large-scale low-level convergence and upper-level divergence of the winds over the SE U.S. was seen in reanalysis data.

[3] The theory presented by B08 suggests that mixed-phase processes should be increased during the middle of the week when pollution is at a maximum. The cloud electrification that leads to lightning is believed to be generated by ice processes in storms, particularly by the charging of riming graupel by ice particle collisions [e.g., Saunders 1994], often associated with vigorously growing clouds that carry water above the zero-isotherm level. Lightning therefore serves as an indicator of the presence of such storms. *Petersen and Rutledge* [1998, 2001], for instance, provide examples of this well known connection. We therefore examined the dependence on the day of the week of lightning statistics in the vicinity of the U.S. using National Lightning Detection Network (NLDN) data. Information about the collection of the data and their accuracy are given by *Cummins et al.* [1998] and *Idone et al.* [1998].

[4] An earlier search for weekly cycles in lightning activity by *Mullayarov et al.* [2005] found evidence in data for 1979–1994 of a midweek peak in activity for areas in the neighborhood of East Siberia and Africa. Numerous other studies of possible weekly variation in atmospheric behavior have appeared in the literature, but the quality of their statistical analyses varies widely and there is insufficient space to review them here.

2. Weekly Cycle in Lightning Over the SE U.S.

[5] The lightning data were provided by the NASA Lightning Imaging Sensor (LIS) instrument team and the LIS data center via the Global Hydrology Resource Center (GHRC). They are in gridded form everywhere within detection range of U.S. antenna stations, with grid box sizes of about 8 km $\times$ 8 km, at 15-minute intervals. Data for summers (June–August) 1998–2009 were analyzed, overlapping the time period examined by B08. The data were current as of 14 Sept 2009. Results reported here, except for Figure 2, are all based on 1998–2006. Some results in the auxiliary material are based on slightly different periods, as discussed there.[4]

[6] We note that it would be possible to carry out the studies described here using data from the LIS on the TRMM satellite, but sample sizes would be considerably smaller than the NLDN data provides.

[7] The strength of a weekly cycle is determined by fitting time-dependent data $r(t)$ to a 7-day sinusoid

$$r(t) = r_0 + r_7 \cos[\omega_7(t - \phi_7)], \quad (1)$$

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[4]Auxiliary materials are available in the HTML. doi:10.1029/2009GL040915.

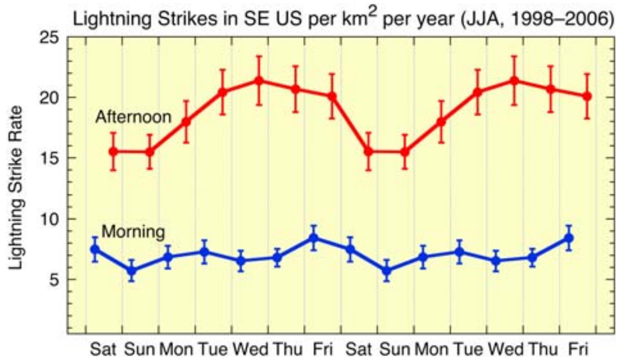

Figure 1. Daily averages of lightning strike rates over the SE U.S. (100W to 80W and 32.5N to 40N) for morning (0000–1200 LT) and afternoon (1200–2400 LT). One-sigma error bars are shown based on week-to-week variance of strike rate.

with $\omega_7 = 2\pi/(7 \text{ days})$, where r_0 is the mean strike rate, r_7 is the amplitude of the cycle, and ϕ_7 is the time during the week when the weekly cycle peaks. By writing $r_7\cos[\omega_7(t - \phi_7)] = c_7 \cos(\omega_7 t) + s_7 \sin(\omega_7 t)$ and using linear-least-squares fits to this version of equation (1) for each week of data, we can use the variance of the coefficients c_7 and s_7 from week to week to estimate the overall uncertainty σ_7 in the amplitude r_7, assuming that the correlation of the coefficients from week to week is negligible and the number of samples for variance estimates (n = 117) is large enough that the coefficients are approximately normally distributed. The ratio r_7^2/σ_7^2 then has a chi-squared distribution with two degrees of freedom. Details are given by B08. The quantity r_7/σ_7 is used as a measure of the signal strength (signal-to-noise ratio). The significance level p of the amplitude r_7, under the null hypothesis that there is no weekly cycle, can be calculated from this ratio as

$$p = \exp\left[-(r_7/\sigma_7)^2\right], \tag{2}$$

as explained by B08. For example, this means that the probability that $r_7 > 1.73\ \sigma_7$ is $p = 0.05$.

[8] Summertime cloud-base temperatures tend to be warmer in the East (which we take to mean east of 100W, roughly the middle of Texas) because of the higher humidity in the East. Cloud depths below the freezing level are correspondingly greater. The potential for warm rain occurring without releasing latent heat of freezing is consequently greater in the East. Therefore, just as done by B08, we first look east of 100W for weekly cycles in lightning activity resulting from the invigoration of storms modified by the weekly cycle in pollution aerosols.

2.1. Weekly Cycle Versus Time of Day

[9] Before investigating the weekly cycle of area-wide lightning activity, it is interesting to examine the strength of the weekly cycle of lightning activity in a way that attempts to show how the cycle strength varies with the level of convective instability. Lightning activity varies strongly with the time of day (local solar time). The time of day when lightning activity peaks is also different in different regions. There are many discussions of the climatology of lightning activity over the U.S. in terms of its seasonal and diurnal variations [see, e.g., *Zajac and Rutledge*, 2001]. Convective instability due to heating by the sun varies with the time of day.

[10] In Figure S1 of the auxiliary material we show how lightning activity varies, on average, with both the time of day and day of the week, for the area with longitudes 100W to 80W and latitudes 32.5N to 40N, covering much of the inland area of the southeastern U.S. This behavior is consistent with the idea that invigoration of storms by aerosols occurs when convective instability is high (afternoons), and not so much in regions where other causes trigger the storms in less convectively unstable conditions (mornings). Though this evidence is suggestive, it is not conclusive, since it is possible that, by accident, the "forcing" of the weekly cycle happens to be weak in those regions where the diurnal cycle peaks in the morning hours.

2.2. Weekly Cycle of Large-Area Averages

[11] In order to compare the strength of the weekly cycle of lightning activity to the weekly cycle in rainfall (averaged over the SE U.S.) seen by B08, we have obtained daily averages of lightning strike rates over an area nearly identical to the "Area B" studied by B08, covering longitudes 100W to 80W and 32.5N to 40N (the northern limit of TRMM satellite coverage). Figure 1 shows the daily averages plotted for each day of the week. Averages use either morning or afternoon hours only. Results have been repeated for a second week to help clarify the nature of the cycles. Error bars are 1-σ in size. Error bars for a particular day of the week are calculated from the variance of daily values for that day and the number of weeks in the sample (117), assuming that strike rates a week apart are statistically independent. There appears to be a strong weekly cycle in afternoon lightning activity, peaking on Wednesday and with a minimum on Saturday/Sunday. Rainfall data from TRMM peaked on Tuesday and was minimum on Saturday, but the TRMM satellite sampling is much less dense than the NLDN system, so differences of this magnitude are not surprising.

[12] The weekly cycle of afternoon lightning activity for averages over the whole of the non-coastal SE U.S. is highly significant, with a significance level p = 0.0074 calculated from (2). This p-value is well under the conventional threshold for statistical significance, p = 0.05. A separate analysis of the time series employing the resampling methods described by B08 found a comparable significance level. The weekly cycle in morning lightning activity is, as one would guess from Figure 1, not statistically significant, with p = 0.54.

2.3. "Never on Sundays," 12 Last Summers

[13] As another indication of how unlikely it is that the weekly cycle of lightning activity is an accident of the unpredictable vagaries of weather, we have obtained the signal-to-noise ratios and phases of average lightning activity over the SE U.S. for each summer from 1998 to 2009, and show the results as a "clock plot" in Figure 2. It can be seen there that the sinusoidal fits peak between Tuesday and

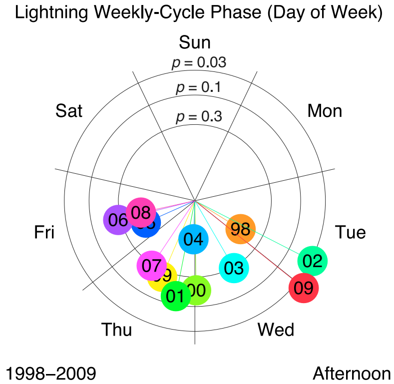

Figure 2. "Clock plot" showing the signal-to-noise ratio r_7/σ_7 (represented by radial distance) and phases (represented by angular sectors) of fits to equation (1) of average lightning activity over the inland SE U.S. for each of 12 summers. Only local afternoon data are used. Radial distances are proportional to r_7/σ_7, which can be converted to significance levels using equation (2) in the main text. The concentric circles are labeled by their corresponding p-levels. Colored balloons contain the last two digits of the years to which they correspond.

Friday for 12 consecutive summers, and never on weekends, despite the large variability in fits to single summers of data.

3. High-Resolution Maps of the Weekly Cycle

[14] We have gridded the lightning data at various resolutions and, at each resolution, obtained the phase ϕ_7 and signal strength (r_7/σ_7) in each grid box based on fits to equation (1). Figure 3 shows a map of such fits at 0.125° resolution, using color to indicate the day of the week when the sinusoidal fit peaks. Weekly cycles seem coherent over larger areas in the eastern half of the country than in the western half. Bands of strong weekly cycles with midweek peaks stretch from Arkansas to Virginia and straddle Iowa and Illinois, and appear to be the source of the strong weekly cycle dominating the large-area averages shown in Figure 1. The weekend (Sat/Sun) peak in rainfall over waters neighboring the SE U.S. seen in TRMM data by B08 is also evident in the lightning data (blue colors). (Note that the detection efficiency of the NLDN system decreases rapidly away from land.)

[15] Figure 3 suggests that there are many locations in the U.S. with cycles significant at the $p = 0.05$ level. A substantial fraction of these cases may very well be spurious: low-probability cases that we have found because of our testing so many grid boxes for a statistically significant weekly cycle. For instance, it would not be surprising that something like 5% of the ($\sim 8 \times 10^4$) boxes show cycles significant at the $p = 0.05$ level that are in fact just "noise". Without a physical theory for the weekly cycle to guide us, we would be hard put, based on statistics alone, to decide whether the weekly cycles with various phases seen in various parts of the country in Figure 3 are "real" or accidents. This is a problem that bedevils much research on detecting weekly cycles when it involves multi-site testing for cycles, particularly using surface station data [*Bell and Rosenfeld*, 2008].

[16] The statistical significance of the cycle seen in Figure 1 for a large-area average suggests strongly that a weekly cycle peaking in the middle of the week occurs over a substantial part of the SE U.S., but we can't be sure that a weekly cycle with a low p-value at any given grid point in Figure 3 is "real". We show in Section S2 of Text S1 of the auxiliary material that even for grid-box sizes of 1° about half of the grid boxes with weekly cycles significant at better than $p = 0.05$ could well be spurious, a reminder that maps like Figure 3 must be examined with a critical eye. The increase in the frequency of occurrence of grid boxes with significant weekly cycles as the grid-box size is increased suggests that while there may be a tendency for a weekly cycle to exist over large areas of the SE U.S., the cycle is probably not very strong at any one place, relative to the "noisiness" of small-scale statistics, and it can only be seen by averaging over many places over long periods.

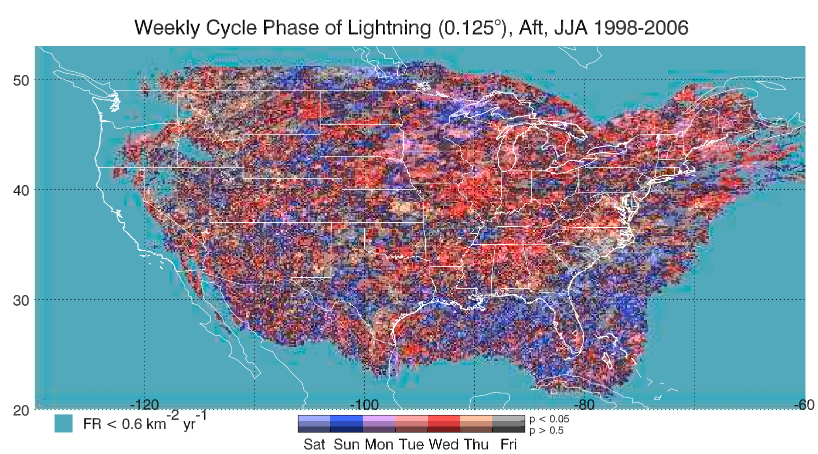

Figure 3. Map of phase and strength of weekly cycle at a resolution of 0.125°. Colors identify both the phase and the signal-to-noise ratio of the cycle. The colors along the top of the color bar indicate local significance levels $p < 0.05$; the darkest colors at the bottom indicate cycles with low significance. Moderately dark colors in the middle indicate significance levels $0.05 < p < 0.5$. Areas with average flash rates (FR) < 0.6 km^{-2} yr^{-1} are masked.

[17] The data west of 100W were also analyzed for weekly cycles, and while there are some signs of a weekly cycle there, they are much smaller, suggesting that, if there are areas with a real but weak weekly cycle, they are not widespread.

[18] Although there seem to be statistically significant weekly cycles present in parts of the SE U.S., it is not immediately evident that strong cycles occur over likely emission areas. In particular, there is no simple correlation with the presence of cities. This phenomenon shows up visually in a map like Figure 3 when the highest-population-density areas are highlighted (not shown here): the colors in the high-population areas tend to be markedly "muddier" than surrounding areas, indicating low signal-to-noise ratios. A more detailed statistical analysis of this phenomenon is presented in Section S3 of Text S1 of the auxiliary material.

[19] The reason for this possible reduction in a weekly signal over the cities is not clear. It may be that pollution levels in these areas are so high that invigoration of storms by pollution is saturated, so that lightning activity goes up and down less with the weekly cycle of pollution than it does over less polluted areas. The possibility of the saturation of pollution effects is discussed, for example, by *Wang* [2005] and *Rosenfeld et al.* [2008]. Or the presence of the city's "heat island" may already be invigorating the storms, leaving little room for any additional effect by the aerosols. Clearly a better analysis of this possibility would involve direct correlations of the strength of the weekly cycle with aerosol concentrations, rather than using the city location itself as a proxy for high pollution levels, since the highest pollution levels may lie downstream of the city. *Jin and Shepherd* [2008] describe an example of such an effort.

4. Possibility of Synoptic-Scale Forcing

[20] It has been suggested (W. A. Petersen, private communication, 2008) that a weekly cycle might be stimulated by a 7-day synoptic-scale modulation of the environment rather than by locally-induced, microphysical pollution-related changes in storm behavior, as suggested above. We searched for such patterns using reanalysis data, as discussed in Section S4 of Text S1 of the auxiliary material. The results were noisy and we could find no convincing evidence of such an effect, other than what was easily attributable to local changes in convective activity.

5. Discussion

[21] Cloud-to-ground lightning-strike data collected in the vicinity of the U.S. for the summer afternoons (1200–2400 LT) of 1998–2009 exhibit weekly variations that are entirely consistent with the observed weekly changes in rain and storm behavior over the SE U.S. obtained from the TRMM satellite and documented by B08. Because of its dependence on ice aloft, lightning activity may more directly reflect the microphysical effects of aerosols on storm development than rainfall. Lightning activity over inland areas in the southeast tends to peak in the middle of the week, while activity over the nearby waters (Atlantic and Gulf of Mexico) tends to peak on weekends. (B08 suggested an explanation of the latter, that storm development is dynamically suppressed over the water due to increases in low-level wind convergence over the nearby land areas due to increased convection.)

[22] The weekly cycle tends to occur in areas where the diurnal variations reach a maximum in the afternoon, when convective instability is highest and the energy for storm development is highest. The apparent diminution of the strength of the weekly cycle over the most populated areas (see Figure S3 in the auxiliary material) and the steady increase in signal strength with areal averaging (see Figure S2) suggest that the weekly cycle might be weak and widespread in the East rather than strong and highly localized. We found no evidence of a weekly cycle in activity in the western half of the U.S. All of this is consistent with the physical theory for the weekly cycle proposed by B08, that midweek increases in aerosol levels cause increased invigoration of storms in regions where convective instability and humidity are high.

[23] The results here and from B08 suggest that, when the environment is right, anthropogenic pollution can cause storms to grow larger than they would otherwise, probably with concomitant increases in damaging severe-storm phenomena. We are now focussing our attention on this question.

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Supplementary Material

S1. Weekly cycle vs. Time of Day

[Please see section 2.1 of the main text for an explanation and discussion of Figure S1.]

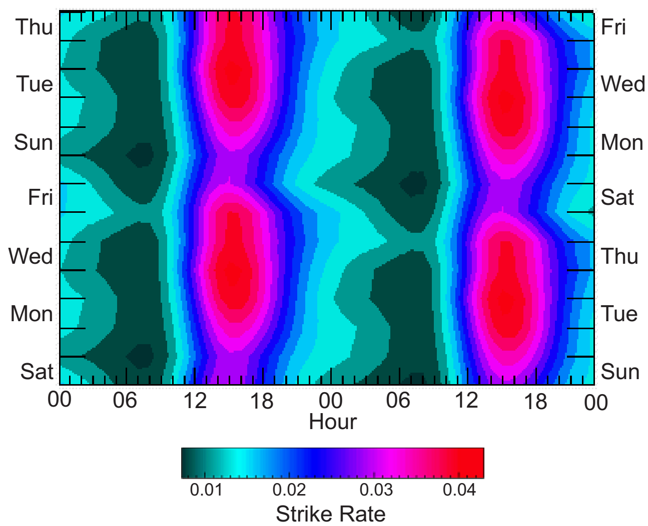

Figure S1: Contour plot showing the average lightning strike rate [in units of $(8\,\mathrm{km})^{-2}(15\,\mathrm{min})^{-1}$] over the inland SE U.S. for each hour and day of the week. Results have been duplicated for an additional 24 hours and 7 days to help clarify the cycles. Note that the days of the week are advanced 1 day in the second 24 hours.

S2. Analysis of weekly cycle at various grid scales

To get some insight into what fraction of the area of the map in Figure 3 might have "real" weekly cycles and what might be consistent with pure noise, we have produced gridded maps of weekly cycle strength at various resolutions and histogrammed the significance values p calculated for each grid box at each resolution. If the estimates of the p–values are good (that is, if our statistical model of the data under the null hypothesis that there is no weekly cycle is good), we would expect that, if there were no actual weekly-cycle signals present in the area, the frequency distribution of p–values we calculate for grid boxes would be perfectly flat, since the probability of obtaining a given p value is just $\text{Prob}(p < p_0) = p_0$, a line with constant slope 1. In other words, the expected number of grid boxes with p-values in a bin of size Δp would be $N\Delta p$ if N is the total number of grid boxes in the map. We show in Figure S2 the frequency distribution (normalized histogram) of p–values for maps at various grid-box resolutions, starting with the resolution $0.125°$ of the map in Figure 3 in the main text and decreasing to a resolution of $2.5°$ grid boxes. Only boxes east of 100W are included, and boxes with low average lightning strike rates are excluded.

As a point of reference, if we were to plot the frequency distribution of p-values for the *diurnal* cycle of lightning at a given grid-box size, almost all the counts would fall in the lowest p bin, because the diurnal-cycle "signal" is typically quite strong and easily detectable at most grid locations.

The one-sigma error bars in Figure S2 are based solely on the number of counts in a bin (bin size $\Delta p = 0.05$), using the estimate $\sigma_f = \sqrt{\Delta p(1 - \Delta p)/N}$ valid if all grid box activity were spatially independent, with N the total number of counts in the histogram. Because of the assumption of spatial independence, these error estimates are quite likely to be underestimates, particularly at higher resolutions, but can serve at least as a lower bound on the true error-bar sizes.

Figure S2 reveals a tendency for more grid boxes to have a significant signal (low p) than we would expect by chance if there were no anthropogenic weekly influence present. Signs of strong weekly cycles (low p) begin to show up clearly when the grid boxes are larger than 1°, and at resolution 2.5° there are more than 3 times as many grid boxes with high significance ($p < 0.05$) as would be expected by chance. The increase in the number of grid boxes with a strong signal-to-noise ratio for larger grid boxes suggests that there is a consistent weekly cycle (peaking on about the same day of the week) at various locations within a grid box extending over the grid-box domain, such that averaging over scales of $\sim$ 100 km reduces the noise level enough that the signal can come out clearly.

As a test of this approach we analyzed the same data for cycles of length 9 days instead of 7. (There are no known physical mechanisms that could generate 9-day cycles.) The frequency distributions at all resolutions fell very close to the $f = 0.05$ line, as would be expected, and display nothing like the peaking at low p–values seen in Figure S2.

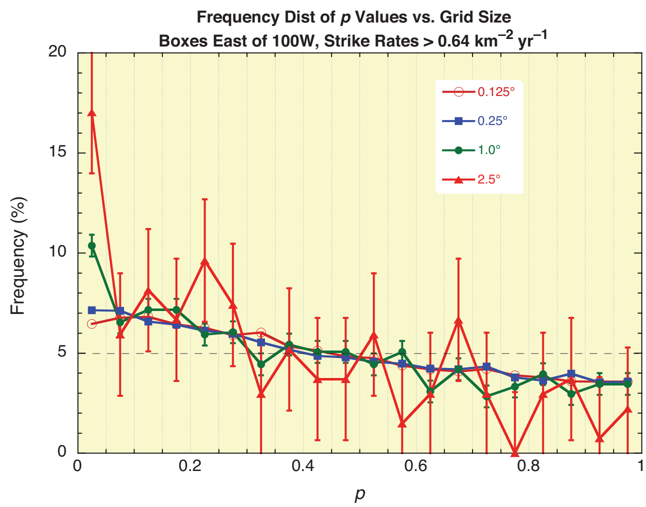

Figure S2: Frequency distributions of significance levels $p = \exp(-r_7^2/\sigma_7^2)$ for grid boxes in maps with various grid sizes ranging from 0.125° to 2.5°. One-sigma error bars are estimated assuming counts in each bin are independent. The distributions would lie along the dashed line at $f = 5\%$ if no weekly cycles were actually present in any of the boxes.

S3. Lack of association of weekly cycle strength with population density

To investigate the correlation of strong weekly cycles (as measured by their signal-to-noise ratios) with population densities, gridded population data were obtained from *CIESEN* (2005) (available at 2.5 arc-minutes resolution) and correlated with the weekly cycle strength as measured by p values. If anything, the strength of the signals seems to decrease immediately over city centers. We show in Figure S3 the frequency distributions of p values of weekly cycles in 0.125° grid boxes for the region with longitudes between 100W and 80W and latitudes between 30N and 40N, for grid boxes with several categories of population densities. For population densities above 460 km^{-2} (red curve), the frequency of strong weekly cycles (as measured by $p < 0.1$) is below average when compared with the distribution for all points in the SE U.S. regardless of population (green curve). If we look at areas with the next lowest population densities (blue curve) the frequency of strong weekly cycles is already approaching something like the average, and casual inspection suggests that this is the case for lower population densities.

S4. Analysis of a synoptic-scale explanation for weekly cycle as an alternative to the aerosol hypothesis

Could it be that the lightning maximum during weekdays is merely a statistical coincidence of more favorable synoptic conditions for lightning during midweek, as was suggested by *W. A. Petersen* [private communication, 2008]? We should consider the possibility that the synoptic situation over the U.S. could be changed on a weekly

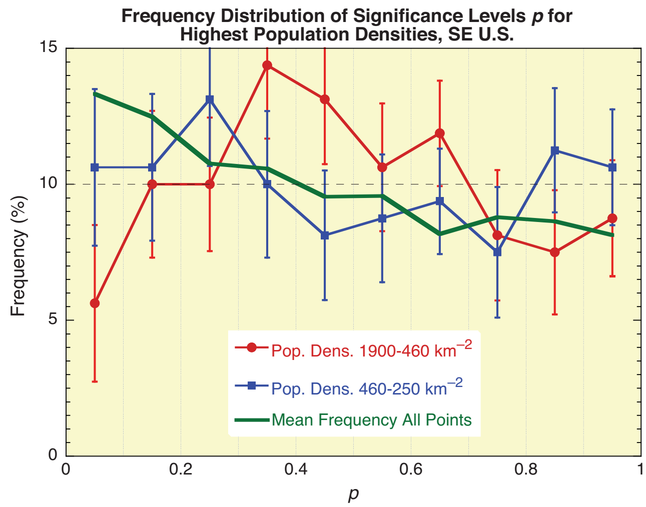

Figure S3: Frequency distribution of significance levels p for 0.125° grid boxes located over the highest population areas (red) and the next highest (blue), and the distribution of p values over all grid boxes regardless of population (green). Weekly cycles with high signal-to-noise ratio (low p) appear to occur less often over cities than they typically do over less populated areas. The two distributions stratified by population density (red, blue) are each based on 160 grid boxes. Because p is sorted into 10 bins, we would expect the frequency distribution to fall on the 10% line (indicated by a dashed line) if no real weekly cycles were present in the region. See the discussion in Section S2 of the Supplementary material.

basis due to human activity. The changes might take the form of either an increased frequency of favorable conditions during the middle of the week, or a tendency for some synoptic situations more conducive to lightning activity to be more intense during the middle of the week, or a combination of the two. (There is, of course, a degree of ambiguity to this issue, since the hypothesized microphysical changes due to aerosol effects could induce local changes in the circulation of the atmosphere that might evolve into synoptic-scale changes, confusing cause and effect.)

The methods suggested by *Lacke et al.* (2009) could in principle provide an answer to this question. They investigated whether increased rainfall is associated with increased aerosol concentrations around Atlanta, Georgia, when only days with synoptic situations favoring tropical-storm-like developments were counted. If synoptic modulations of the environment were the sole cause of the weekly cycle, this type of averaging should eliminate the weekly cycle in the averages. The analysis by *Lacke et al.* (2009) appeared to show that a weekly cycle is still present when only days with similar synoptic conditions are counted, but the amount of data and the statistical methods used make the conclusions somewhat uncertain. This study nevertheless represents a good first attempt at answering this question.

Our approach to this question was to examine the variability in the synoptic parameters that are best correlated with the lightning activity. A parameter that has a high correlation was found to be the temperature at the height of 850 hPa (T850) at 00Z. The correlation between T850 and the number of lightning strokes during the 24 hours starting at 00Z was calculated separately and independently for each $2.5^\circ \times 2.5^\circ$ grid box, for all the summer (JJA) days during the years 1998-2007 (See Figure S4). It appears that the correlation is positive in the parts of North America that are affected by Gulf and Atlantic moisture, and negative in the western deserts.

The differences in frequency of lightning midweek (WTF) minus weekend (SSM) was calculated for the coolest, middle and warmest thirds of T850, presented in the top to bottom panels of Figure S5, respectively. (Since 00Z corresponds roughly to 1800 LST the previous day over the SE U.S. and the weekly cycle is far stronger during afternoon hours, we have used WTF averages to represent the midweek period instead of TWT.) The same was done for the geopotential height at 500 hPa (H500), which is the second parameter that is correlated with summer lightning activity, as shown in Figures S6 and S7, respectively.

The partitioning of T850 and H500 into terciles helps eliminate much of the synoptically induced changes in lightning statistics within a given tercile, to the extent that the synoptic changes are changes in frequency rather than in intensity. Using finer subdivisions than terciles would handle any changes in intensity distributions of the parameters with the day of the week, but the amount of data available precludes this. If lightning activity were determined by synoptic-scale changes, no weekly cycle should appear in Figures S5 and S7. The first tercile (top panel of Figures S5 and S7) has the lowest cycle of lightning activity in the central and eastern USA, whereas the third tercile (bottom panel of Figures S5 and S7) has the highest cycle of lightning activity there. According to these figures, the coolest T850 and lowest H500 have the least indicated weekly cycle in the lightning, which is confined to the SE USA. The weekly cycle intensifies and expands northward with the warmer T850 and higher H500 conditions. Here we see that the weekly cycle emerges during conditions that are, to some extent, "synoptically homogenized" for T850 and H500, the synoptic parameters that can best explain variability in the lightning. Furthermore, we can see a systematic behavior where, in the conditions that are synoptically more conducive to lightning, the weekly cycle becomes stronger and expands northward.

A second approach to the question of whether the weekly cycle in lightning activity can be explained by a weekly cycle in synoptic patterns would be to ask whether a weekly shift in synoptic patterns is detectable in the data. We have therefore analyzed the statistics of maps of the weekly differences of WTF and SSM averages on a $2.5° \times 2.5°$ grid. For each grid box we calculated the significance level p of the WTF–SSM difference using a t–test based on the number of weeks of data. The t–test gives the probability that the WTF–SSM difference for a grid box could have occurred by chance, based on the natural variability of the differences estimated from the variations of each summer's average difference, under the null hypothesis that there is no change in the means with the day of the week. If the null hypothesis is correct, the frequency distribution of p-values should be uniform, independent of p, as explained in Section S2.

We show in Figure S8a the frequency distribution of p-values of the WTF–SSM differences of 850-hPa temperatures for grid boxes lying in the region depicted in Figure S4. The error bars are estimated from the variability of the frequency distributions for each summer individually. Since the bin size for the histograms is $\Delta p = 0.05$, we would expect the frequency distribution to be centered around 5%, under the null hypothesis, and this is indeed what we see. This indicates that without additional information the maps are useless for identifying a weekly cycle in the T850 fields.

The same is true of the geopotential height field at 500 hPa. Figure S8b shows that the frequency distributions of p-values of the height field at this grid resolution are entirely consistent with there being no weekly cycle. Thus, an attempt to look for a change in the statistics of synoptic patterns with the day of the week is highly vulnerable to mistakenly identifying an apparent weekly anomaly as a sign of a weekly cycle when it is actually an accident of sampling.

References

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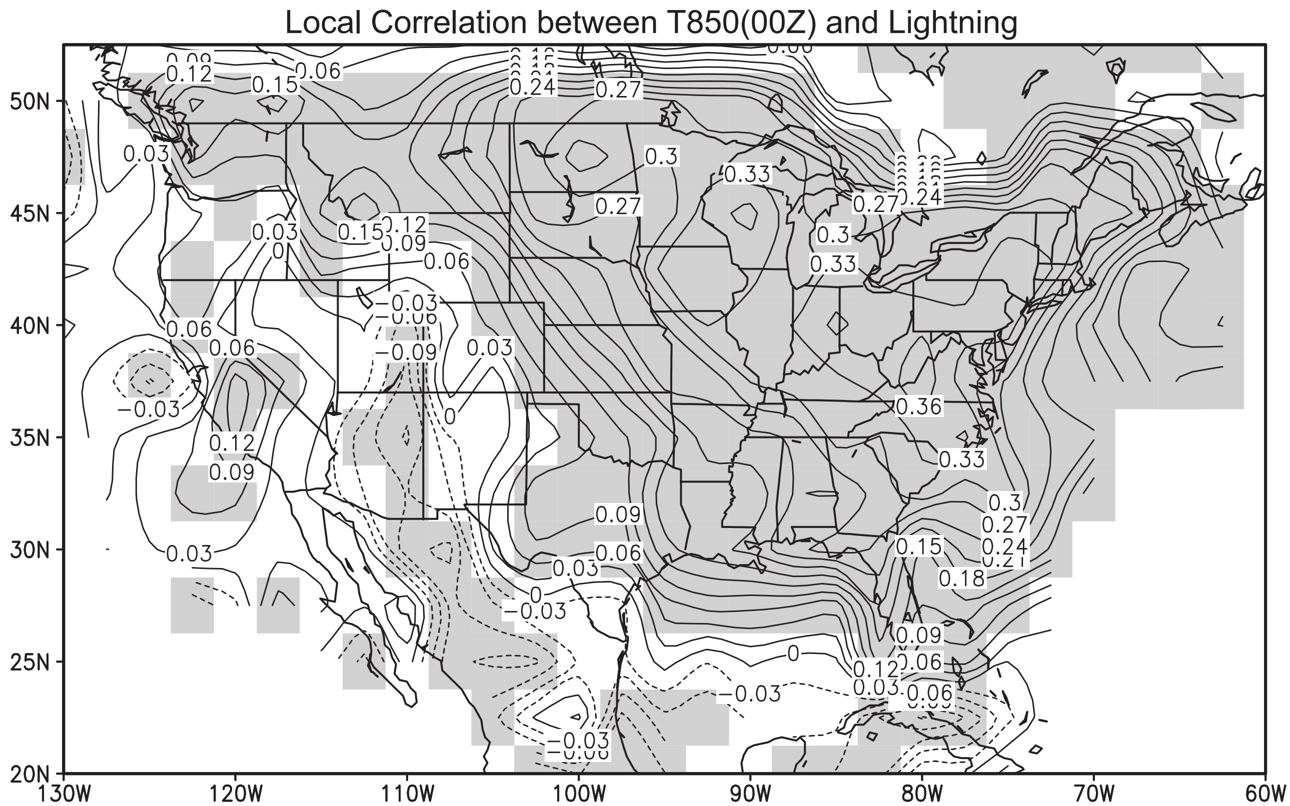

Figure S4: The local correlation between 850-hPa temperatures at 00Z and lightning activity for the subsequent day (00Z–24Z). The correlations in the shaded areas are significant at $p < 0.05$. Note that 00Z corresponds to about 6PM the previous day in the SE U.S.

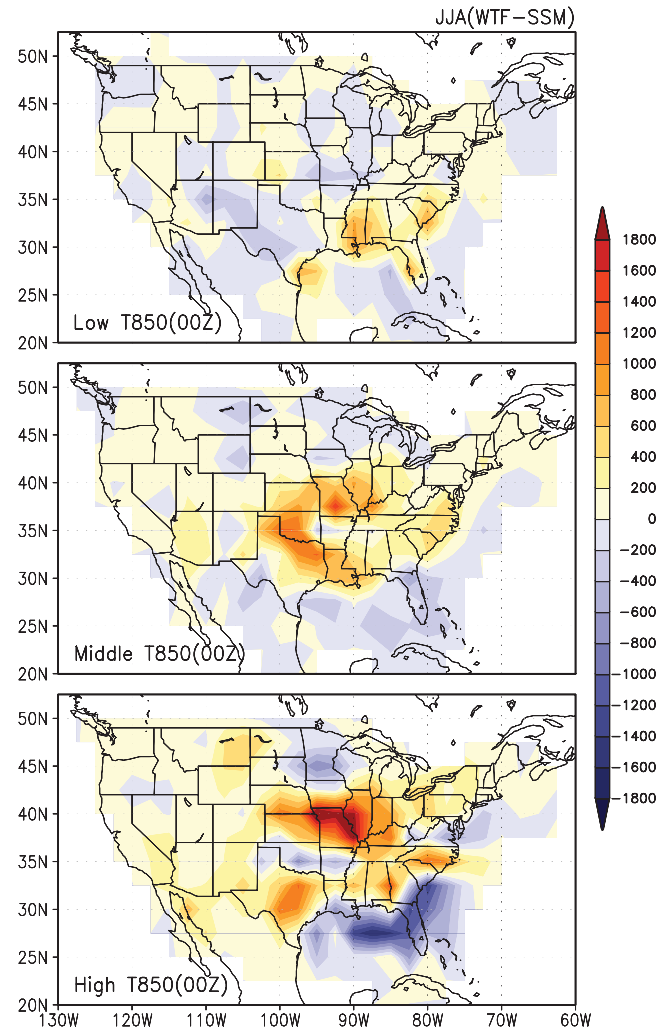

Figure S5: The differences in the lightning frequency of weekdays (WTF) minus weekend (SSM), during the summer months (JJA) of 1998-2007. The anomalies are calculated for the coolest, middle and warmest thirds of T850, presented in the top to bottom panels, respectively. [Units are in lightning flashes per $2.5° \times 2.5°$ grid box].

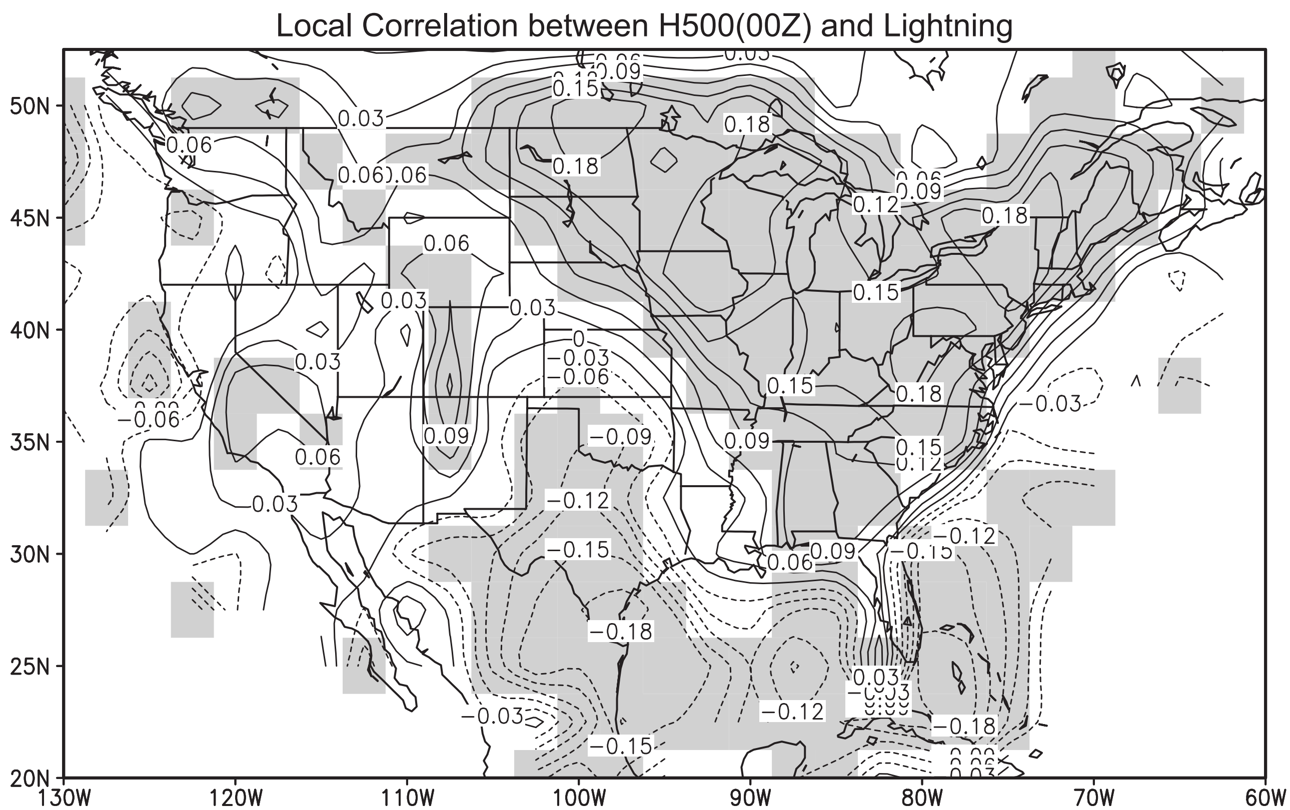

Figure S6: Same as Fig. S4, but for the 500-hPa heights.

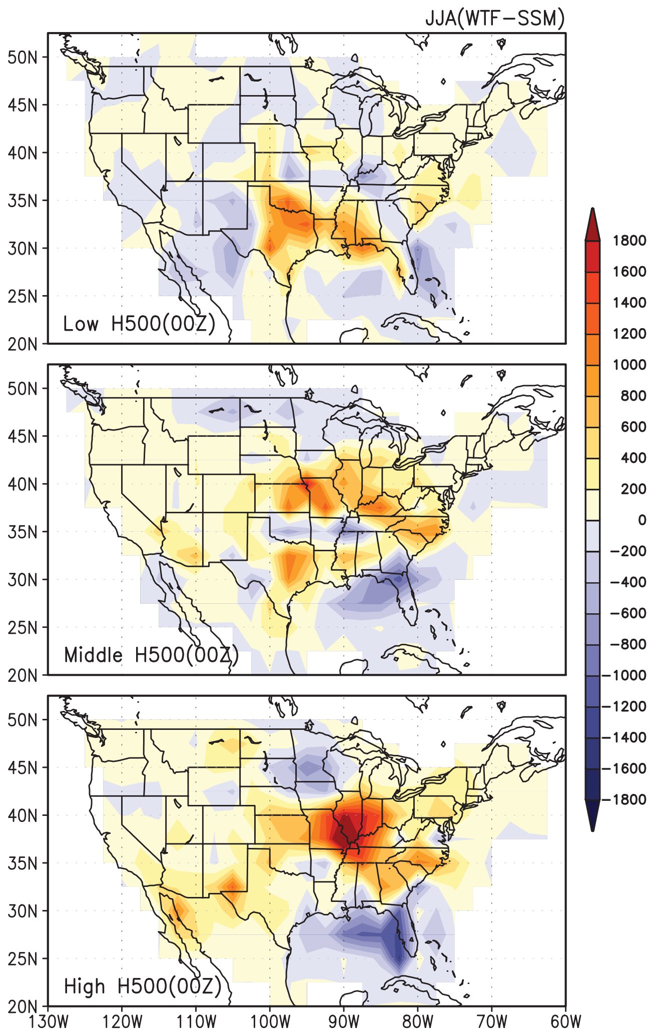

Figure S7: Same as Fig. S5, but for 500-hPa geopotential height.

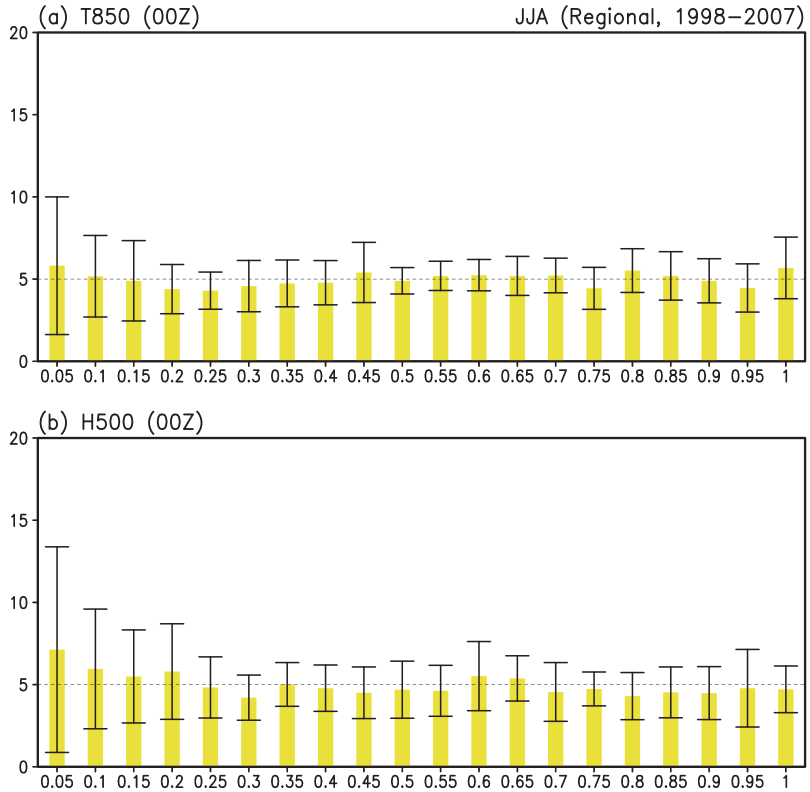

Figure S8: Frequency distribution of grid-box values of p for the significance levels of WTF–SSM differences at each grid box for summers 1998–2007 over the region depicted in Figure S4, for $2.5° \times 2.5°$ grid boxes. Error bars are estimated 1-σ confidence limits. Deviations of the frequency from 5% at small p would indicate the presence of a weekly cycle in some grid boxes. (a) Distribution for NCEP reanalysis 850-hPa temperature field; (b) Distribution for 500-hPa geopotential height field. Both distributions are consistent with the null hypothesis that no "real" weekly cycle is present anywhere.